To: Foss, Scott[sfoss@blm.gov]
From: James Kirkland
Sent: 2017-05-26T11:12:05-04:00
Importance: Normal
Subject: Re: SVP comments on Bears Ears and Grand Staircase
Received: 2017-05-26T11:12:23-04:00
Bears Ears Morrison Inv report final 2017.pdf

You will get the full report next week. But.....
Jim

On Fri, May 26, 2017 at 7:11 AM, Foss, Scott <sfoss@blm.gov> wrote:

David,

Thank you for sharing the letter. It is a well organized summary of what we know so far about paleontological resources in both Bears Ears and Grand Staircase Escalante National Monuments.

Scott E. Foss, PhD
BLM Senior Paleontologist
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sfoss@blm.gov, 202-912-7253

On Thu, May 25, 2017 at 9:31 PM, Polly, P. David <pdpolly@indiana.edu> wrote:

Dear Scott, Vince, ReBecca, Alan, and Jim,
We just submitted comments from SVP for the review of national monument boundaries since 1996. For now we have only commented on Bears Ears and Grand Staircase-Escalante because of the short deadline imposed by the White House for recommendations on those two properties. As you might imagine, SVP is against shrinking the boundaries of either monument because of the important paleontological resources there, and we are in favor of expanding the boundaries of Bears Ears.

I presume everyone except Jim will eventually get a copy of our comments, but I am attaching them here so you will have them if needed.

Thank you all for the service you provide to the science of paleontology through your jobs. As our comments indicate, good public land management is invaluable to paleontology.

With very best wishes,
David

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A PARTIAL INVENTORY OF PALEONTOLOGICAL RESOURCES IN THE MORRISON FORMATION AND ITS BOUNDING STRATA ON THE WESTERN SIDE OF THE BLANDING BASIN, SOUTHWEST OF BLANDING, SAN JUAN COUNTY, UTAH

Prepared for the Bureau of Land Management

2017

by

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A PARTIAL INVENTORY OF PALEONTOLOGICAL RESOURCES IN THE MORRISON FORMATION AND ITS BOUNDING STRATA ON THE WESTERN SIDE OF THE BLANDING BASIN, SOUTHWEST OF BLANDING, SAN JUAN COUNTY, UTAH

Summary

The U.S. Bureau of Land Management (BLM) requested that the Utah Geological Survey (UGS) paleontology team conduct a preliminary inventory of paleontological resources within the Upper Jurassic (Morrison Formation) outcrop belt on the west side of US 191 on the west side of the Paradox Basin (figure 1). We partnered with the BLM to conduct a paleontological

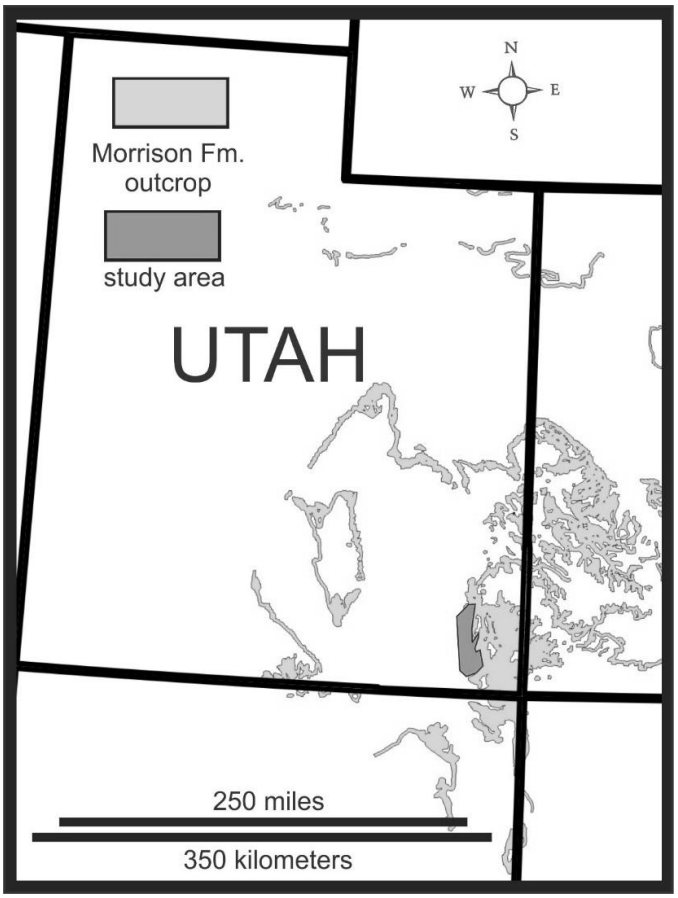

Figure 1. The Morrison Formation outcrop belt in Utah and the Four Corners region with the location of the Blanding Basin study area indicated.

inventory of a portion of an area west of Blanding, Utah that was slated to be included within a then proposed Bears Ears National Monument. The Bears Ears National Monument was established in December 2016, in part to protect sensitive antiquities including fossil resources.

This area was chosen for survey because the State Paleontological Database, managed by the UGS, indicated that few sites had been recorded in this area. Geologic maps showed that fossiliferous rocks of Late Jurassic Morrison Formation and Early Cretaceous Burro Canyon Formation crop out in this region. The Morrison Formation in this region is critical for understanding Upper Jurassic stratigraphy across the southern Colorado Plateau because it is the type area for several important stratigraphic units including the Bluff Sandstone, and Recapture, Westwater, and Brushy Basin Members, and there has been disagreement about stratigraphic nomenclature and correlation of these units (as discussed below). During 10 days of field work in August and September 2016, UGS personnel recorded 35 new fossil localities. Some sites yielding dinosaur bones were found in the Recapture Member indicating the potential for significant sites in this unit. The Brushy Basin Member is well known for preserving abundant vertebrate fossils and many localities were discovered during this project. Many sites contained isolated sauropod bones and one site had many bones eroding out over a small area that warrants additional exploration. Several sites have the potential to produce vertebrate microfossils. One site is a multi-meter-thick plant debris bed, likely representing a marsh setting, that has numerous compressional plant fossils and petrified wood, in addition to bones and bone fragments. This site is quite unusual for the Morrison Formation and resembles deposits better known in the Upper Cretaceous of the western U.S. and Canada. One laterally extensive organic mudstone near the top of the Morrison Formation preserves a 10-cm thick volcanic ash that was sampled for palynology and radiometric dating and, while reliably dated at 150.62 $\pm$ 3.2 Ma, was found to be barren of palynomorphs. We spent only a limited amount of time prospecting the Burro Canyon Formation and no vertebrate localities were found. Although one site in the Morrison Formation, found by the BLM, had been vandalized by unauthorized excavation, it appears less vandalised than the Morrison Formation in other areas of the state.

Methods

Prospecting for paleontological sites was conducted by UGS paleontologists Kirkland and DeBlieux, who together have approximately 75 years of field paleontological experience. On four days, we were accompanied by BLM intern Kevin Maximus Madalena. We followed the standard practice of traversing benches laterally looking for fossil fragments. When fossil material was located, closer examination was made and additional fossil fragments were traced up slope to determine the source of the fossils. Upon locating the site, photographs were taken, and its location was determined using topographic maps and GPS. Additionally, utilizing UGS locality forms as a template, geological data about the site was documented. In general, we follow best practices for mitigation developed by the UGS and the Society of Vertebrate Paleontology (Kirkland and Foster, 2006; U.S. Bureau of Land Management, 2008; Society of Vertebrate Paleontology, 2010; Murphey and others, 2014). Because the study area consists of approximately 150 square miles of rugged and often difficult to access terrain with varying degrees of cover (figure 2), we recognized that only a small portion of this area could be examined within the scope of this project. Therefore, we examined areas with the least amount of cover and easiest access. Eleven areas of exposed strata scattered throughout the study area were traversed covering just over 900 acres (figure 2). Furthermore, we used taphofacies analysis to identify unusual local environments where rare small vertebrates or plant remains may be found (e.g., Kirkland, 2006). Using these methods, approximately 900 acres were inventoried for significant fossil sites (appendix 1). We note that even within the areas examined it is not

possible to locate every potential site, because a fossil locality may be very subtle and in some cases significant fossils may crumble to dust before being exposed on the surface.

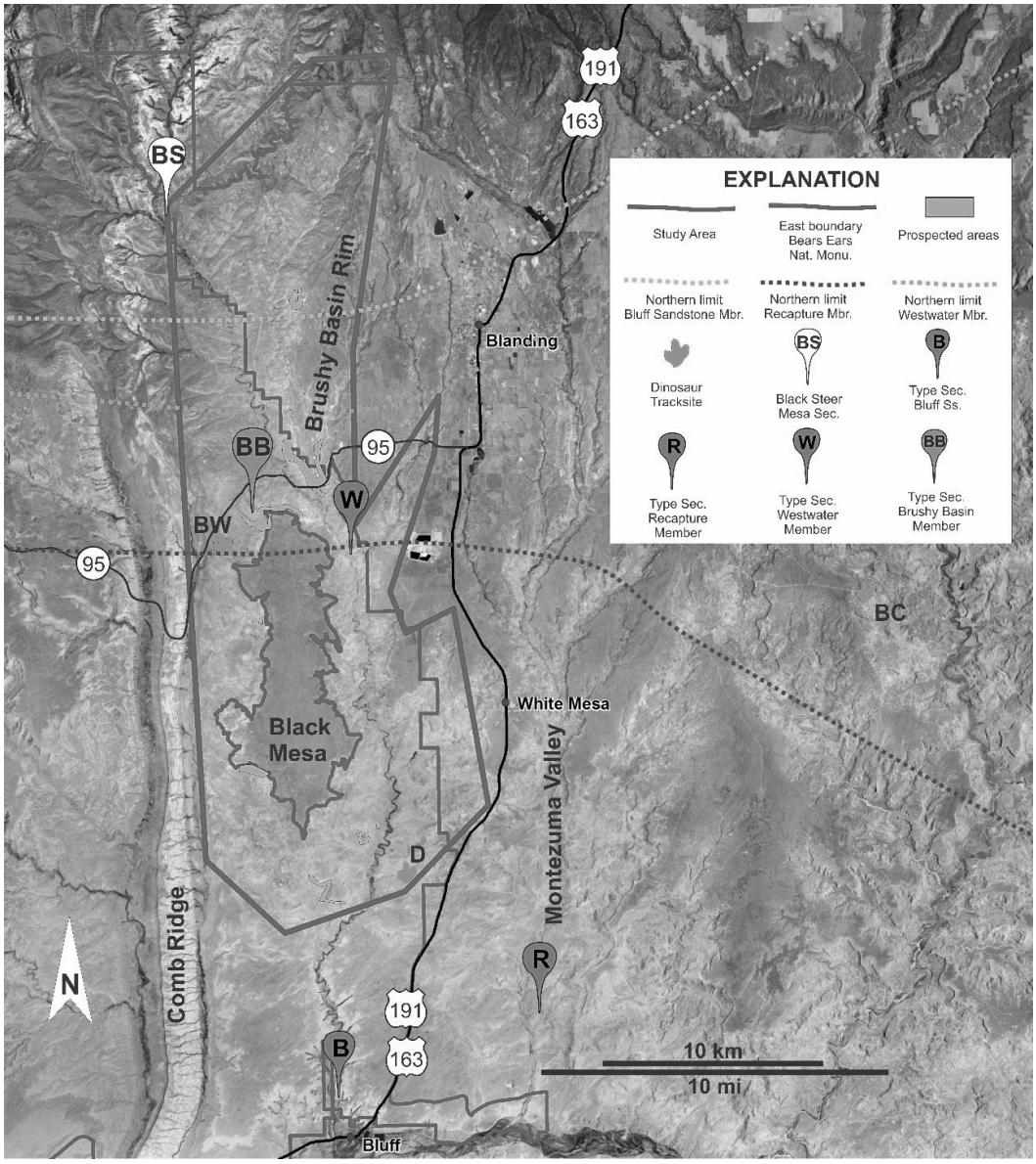

Figure 2. Study area on the west side of the Blanding Basin with locations of type sections of members of the Morrison Formation noted. The Butler Wash (BW) tracksite (Lockley and Mickelson, 1997), the *Deltapodus* (D) site (Milán and Chiappe, 2009), and a unionid bivalve site in the Salt Wash Member in Black Steer Mesa section (BS) (Cadigan, 1955) are the only paleontological localities published on within the study area. Utah's only vertebrate site in the overlying Lower Cretaceous Burro Canyon Formation (BC) is indicated (Milán and others, 2015). Northern limits of lower members of Morrison Formation after Anderson (1998, 2000).

Morrison Formation

The Morrison Formation is probably the most famous Jurassic-age dinosaur-bearing unit in the world, being the subject of more than 150 years of dedicated paleontological research (Dodson and others, 1980; Morales, 1996; Carpenter and others, 1998; Turner and Peterson, 1999, 2004; Foster, 2003, 2007; Foster and Lucas, 2006). The Morrison was initially named for dinosaur-bearing strata along the Colorado Front Range by Cross (1894). Pipiringos and O'Sullivan (1978) noted that across the Colorado Plateau the Morrison unconformably overlies the San Rafael Group on the J-5 unconformity and is in turn unconformably (K-1 unconformity) overlain by the Lower Cretaceous Burro Canyon Formation in the Blanding Basin and the Cedar Mountain Formation farther to the north in Utah (Stokes, 1952). We do not recognize the presence of the J-5 unconformity at the base of the Morrison Formation but instead interpret the contact as representing the transition from subtidal (Summerville Formation) to supratidal in an arid clastic sabhka environment, and that the reported erosional indicator (unconformity) is just a result of the higher energy coastal setting. The Morrison Formation on the west side of the Blanding Basin is a critical series of exposures for understanding Upper Jurassic stratigraphy across the southern Colorado Plateau. It is the type area for several important stratigraphic units (figures 2, 3) (Gregory, 1938; Anderson and Lucas, 1998).

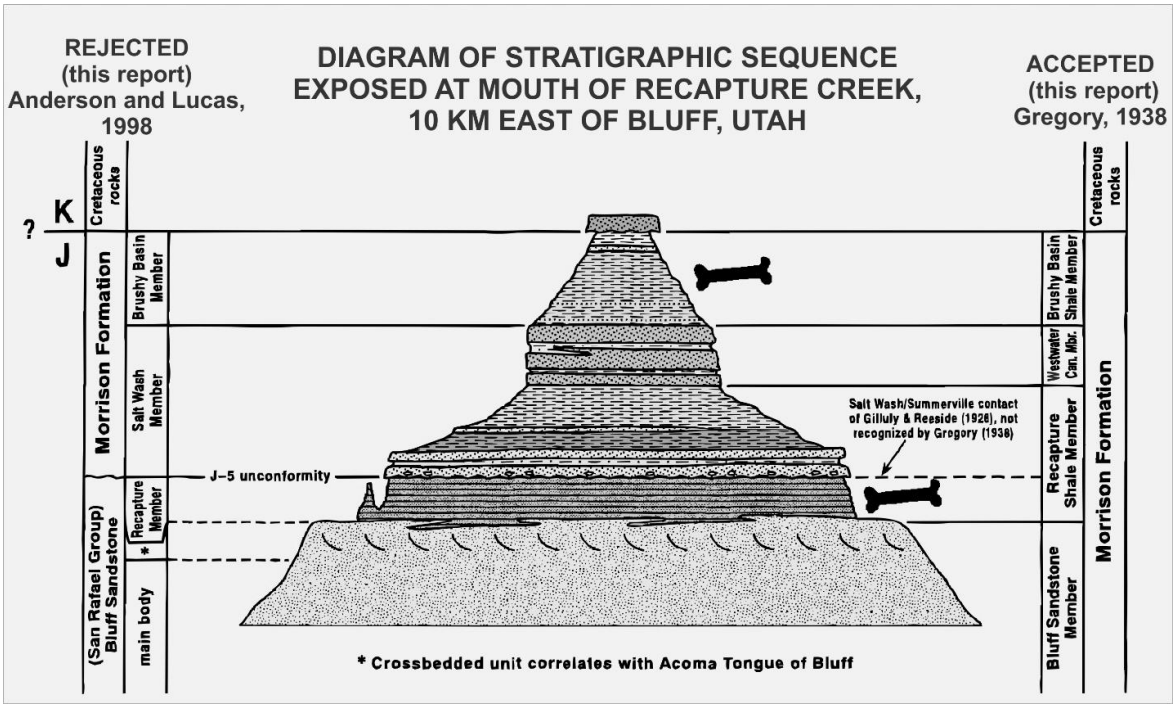

Figure 3. Comparison of stratigraphic interpretations of Gregory (1938 and Anderson and Lucas (1998) of the Morrison Formation in the western Blanding Basin, noting that we favor the initial interpretation of Gregory. Modified after Anderson and Lucas (1998). Rejected stratigraphic interpretation of the western Blanding Basin proposed by Anderson and Lucas (1998). Bone symbol indicates general levels where dinosaur bones were discovered during our study.

It is notable that the stratigraphic nomenclature in the southern part of the study area is significantly different than that in the northern portion of the study area. The definitions of these stratigraphic units and their relationship across the area have been an issue hotly debated between two groups of researchers: (1) the U.S. Geological Survey (figure 4) largely centered around the research of Fred (Pete) Peterson and Christine Turner (Peterson, 1988, 1994; Turner and Fishman, 1991; Turner and Peterson, 2004), and (2) a New Mexico group (figure 3) largely centered around the research of Orin Anderson, New Mexico Bureau of Mines and Mineral Resources and Spencer Lucas, New Mexico Museum of Natural History and Science (Anderson and Lucas, 1996, 1998).

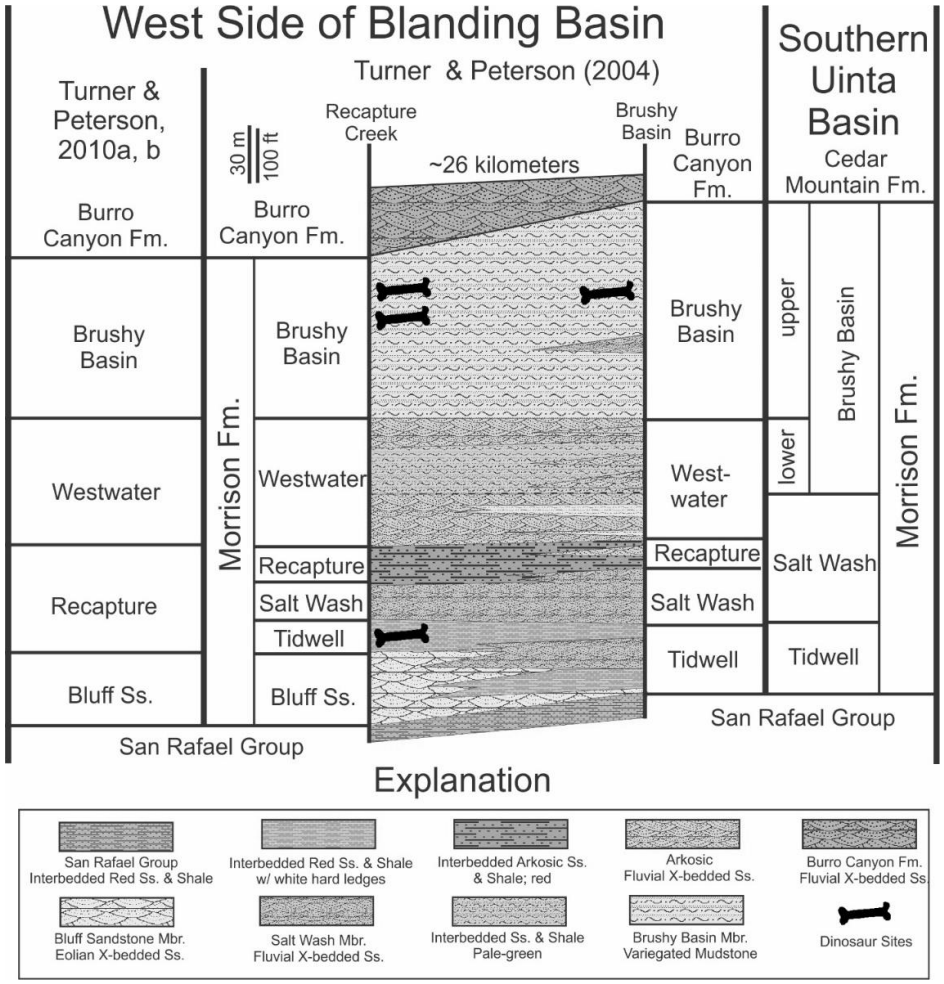

Figure 4. Mid Mesozoic stratigraphy in the western Blanding Basin vs. the southern Uinta Basin. Modified after Turner and Peterson (2004) with updated interpretation of the Recapture Creek area (Turner and Peterson, 2010a, b) followed during this study. Bone symbol indicates general levels where dinosaur bones were discovered during this study.

Even after 10 days in the field, we had difficulty discerning stratigraphic relationships. On March 4th, 2017, Kirkland had an opportunity to meet with Christine Turner to discuss the stratigraphy in this area. She noted that recent observations by Robert O'Sullivan (2010a, b) of the U.S. Geological Survey team at the type Recapture section (figures 2-4) support the interpretation that in this immediate area the basal Tidwell Member is laterally equivalent to the Bluff Sandstone and the Salt Wash Member onlaps the Bluff Sandstone such that the Recapture Member rests directly on the Bluff Sandstone in its type area (Turner and Peterson, 2010a, b; verbal communication 2017). It is within this stratigraphic framework that we discuss the fossil occurrences discussed herein (figures 4, 5). However, our cursory investigation of these strata across the area indicates that these stratigraphic relationships could be better discerned by a dedicated stratigraphic research project that would make a fine Master's or Ph.D. project.

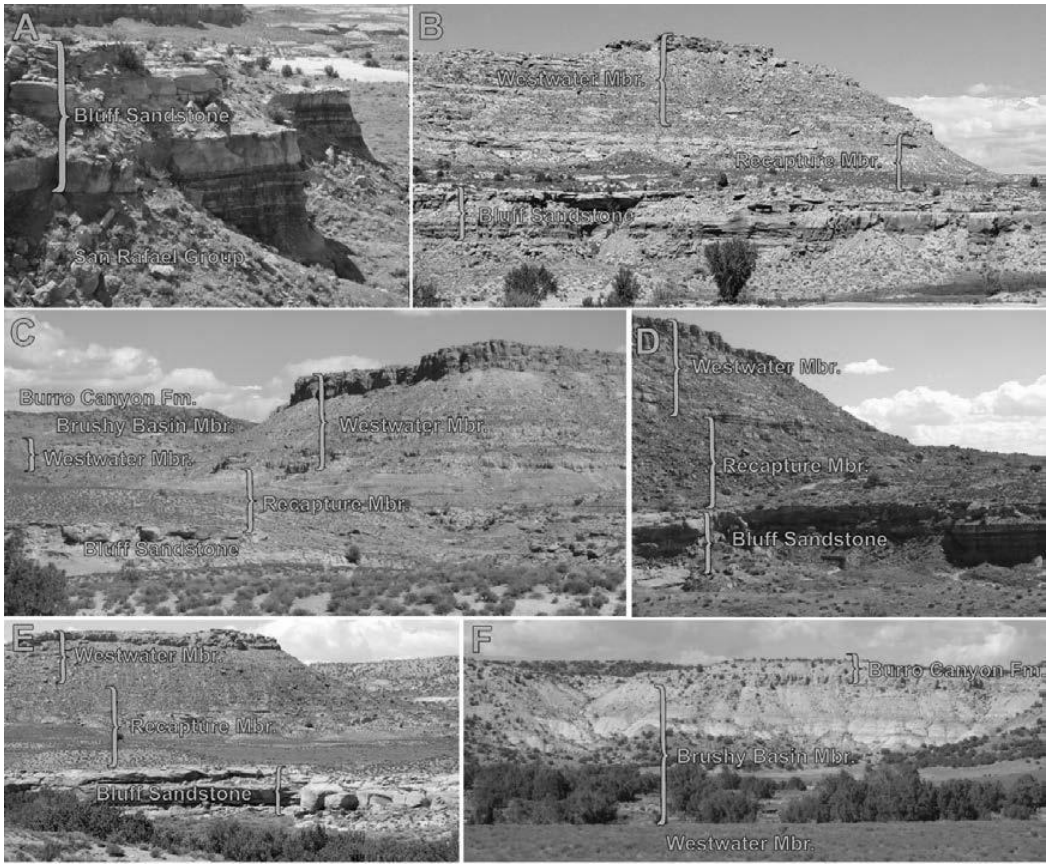

Figure 5. Morrison Formation in the western Blanding Basin in the southern Black Mesa area. (A) Bluff Sandstone Member of the Morrison Formation sitting above the San Rafael Group south of No Mans Island looking south. (B) Lower members of the Morrison Formation on western side Decker Cove. View toward west. (C) Morrison Formation and Burro Canyon Formation strata on west side of No Mans Island and at the south end of Black Mesa from the south. (D) Morrison Formation lower members in Decker Cove. View looking east. (E) Lower Morrison Formation strata at the south end of Black Mesa. View looking west. (F) Well exposed Brushy Basin Member of the Morrison Formation strata on the top of the south end of Black Mesa. View toward north.

Bluff Sandstone

Gregory (1938) described the Bluff Sandstone as the basal member of the Morrison Formation following the usage of Baker and others (1936) from outcrops at the top of the Middle Jurassic Summerville Formation of the San Rafael Group on either side of the San Juan River near Bluff, Utah. We interpret the type section to have been in an alcove to the northeast of Bluff, Utah (figure 2) based on the photograph of his team surveying the Bluff Sandstone (Gregory, 1938, pl. 3C). Gregory described the Bluff Sandstone as follows:

> "The Bluff sandstone member is white, brown-stained, commonly cross-bedded, and made up of medium to coarse quartz grains. Typically it is one massive bed 200 to 350 feet thick that here and there includes aggregates of large quartz grains, clay balls, and short thin lenses of red mudstone. In some places it is arranged as long overlapping sandstone wedges bordered by a little red shale, and in other places as poorly defined beds 20 to 40 feet thick. Traced eastward, the Bluff sandstone that forms the top of Tank Mesa is less persistently massive. Near the mouth of Montezuma Canyon 10 to 20 feet of bedded white sandstone are incorporated in red sandy shale that thins, thickens, bunches up, or flattens out along the strike. Traced northward along Butler Wash and Cottonwood Canyon the Bluff sandstone is represented in places by three or more beds."

Peterson (1994) interpreted the Bluff Sandstone to represent a coastal eolian unit. Craig and others (1955) noted that it interfingers with the underlying Summerville Formation and the overlying Morrison Formation and thus is transitional between the two stratigraphic units. O'Sullivan and Maberry (1975) had identified trace fossils (interpreted as having marine origins) in their basal unit A of the Bluff Sandstone near the Arizona border and indicated that this supported a genetic link with the underlying San Rafael Group. These observations preclude the presence of a J-5 unconformity either above or below the Bluff Sandstone and Anderson and Lucas (1996, 1998) removed it from the Morrison Formation and included it as part of the underlying San Rafael Group. The underlying Summerville strata are identified as its correlative Wanakah Formation underlying the J-5 unconformity by O'Sullivan (2010a, 2010b). Anderson and Lucas (1996, 1998) correlated the Bluff Sandstone to similar eolian units (Zuni and Cow Springs Sandstones) to the south in New Mexico and Arizona that occur at the top of the Middle Jurassic San Rafael Group. The basal unit A of the Bluff Sandstone preserving "marine" burrows (O'Sullivan and Maberry, 1975) is now referred to as the Horse Mesa Member of the Wanakah Formation (Condon and Hoffman, 1988; O'Sullivan, 2010b). O'Sullivan (1998) documented the Bluff Sandstone pinching out into the Tidwell Member of the Morrison north of State Route 95 with the underlying Horse Mesa Member of the Wanakah Formation extending to the north end of the study area (figure 2).

Turner and Peterson (2004) reported the Bluff Sandstone unconformably overlies the San Rafael Group and that the Bluff Sandstone Member of the Morrison Formation interfingers with and is overlain by the Tidwell Member. Subsequently, Turner and Peterson (2010a, b; verbal communication 2017) have revised this interpretation following O'Sullivan (1998; 2010a, b) in recognizing that the Recapture Member directly overlies and intertongues with the Bluff Sandstone in the area around Recapture Creek and the south side of Black Mesa, suggesting that both the Tidwell and Salt Wash Members were laterally equivalent to the Bluff Sandstone. We

observed isolated eolian lenses (dunes) in the lower part of the overlying Recapture Member south of Black Mesa, which supports the observation of both research groups that the Bluff Sandstone of the Morrison Formation is genetically associated with the basal Recapture Member (Anderson and Lucas, 1996, 1998; Turner and Peterson 2010a, b).

No fossils were observed in the Bluff Sandstone during this study, although these strata are likely to preserve invertebrate trace fossils and perhaps even dinosaur tracks elsewhere. The Butler Wash Dinosaur Tracksite (figure 2**)** on the northwest side of Black Mesa was initially described as being immediately below the Bluff Sandstone (Lockley and Mickelson, 1997), but we identify it as at the top of the Butler Wash Sandstone bed of the Wanakah Formation which O'Sullivan correlates with the Moab Tongue of the Curtis Formation putting the J-3 unconformity in the middle of the Wanakah (O'Sullivan, 1992, 1998, 2000, 2010a, b). In keeping with the Utah Geological Survey Mapping Program's position, strata between the Morrison Formation and the Moab Tongue is mapped as Summerville Formation. In keeping with this the Horse Mesa Member would be considered part of the Summerville Formation. A full analysis of the usage of the Wanakah Formation in Utah is needed but is beyond the scope of this project.

Recapture Member

The type section of the Recapture Member is on Recapture Creek northeast of Bluff, Utah (figure 1). It is well developed across the southern portion of the study area (figure 5, 6). Gregory (1938) summarized the properties of the Recapture Member as follows:

> "The interval between the Bluff sandstone member and the lowermost bed characteristic of the Westwater Canyon sandstone member is occupied by a series of strongly colored shales and sandstones 100 to 300 feet thick. They appear in many places as sloping platforms at the base of cliffs and are particularly well displayed near the mouth of Recapture Creek, from which the name is derived. The shales are prevailingly dark red, but some are variegated pink, ash, brown, and gray. Many of them include firm, strongly calcareous beds that break into slabs and friable, imbricated gypsiferous beds that weather as tiny cliffs. The sandstones are white beds of glistening quartz cemented by lime, few of them more than a foot thick or continuous for more than 1,000 feet…. The shales and sandstones combine to form slopes, low mesas, and platforms, and the edges of sandstone beds appear as shelves and small benches. The outcrops are attractively color-banded, but as the shale and sandstone feather out and replace each other along the strike the arrangement of sections 1,000 feet apart is quite different."

Gregory (1938) noted that the Recapture Member averages about 60 m (200 ft) thick throughout the region. Stokes (1944) noted that the Recapture interfingers with the Salt Wash Member laterally. Craig and others (1955) recognized that the Recapture Member thickens to the south and appears to have been sourced from the south as is the overlying and genetically related Westwater Member. An apparent Salt Wash tongue was thought to split the Recapture into upper (Recapture Member) and lower (Tidwell Member) members in the southern part of the study area (Peterson and Turner-Peterson, 1987; Turner and Peterson, 2004). Thus in 2004, the USGS divided the Morrison Formation into: (1) Bluff Sandstone, (2) Tidwell Member, (3) Salt Wash Member, (4) Recapture Member, (5) Westwater Member, and (6) Brushy Basin Member (figure 4, 5).

Figure 6. Dinosaur bone localities in the Recapture Member of the Morrison Formation in the area around No Mans Island on the western side of the Blanding Basin. (A) Overview of locality Sa1115v on the west side of No Mans Island toward north. (B) Sa1115v, view looking northwest. (C) View of bone bearing strata at Sa1115v. (D, E) Close up of dinosaur bone in situ at Sa1115v. (F) Close up dinosaur bone and fragments on slope at Sa1115v at the location shown in (C). (G) Overview of locality Sa1132v just west of H. (H) Lower Morrison Formation strata on south side of No Mans Island looking north. (H) Overview of locality Sa1131v just east of H.

Anderson and Lucas (1996, 1998) restricted the Recapture Member to the lower interval as a member of the Bluff Sandstone of the San Rafael Group and included the upper interval into an expanded Salt Wash Member (figure 3). In their system, the Morrison is restricted to a lower fluvial-sandstone-dominated Salt Wash Member and an upper variegated-mudstone-dominated Brushy Basin Member. To some degree this followed the way Craig and others (1955) split the Morrison for their analysis of the distribution of facies and sedimentological properties, although they never proposed combining these rock units.

In 2010, Turner and Peterson (2010a, b, verbal discussion, 2017) followed O'Sullivan (1998, 2000, 2010a, b) in recognizing that the Recapture Member along the southwest side of the Blanding Basin rests directly on, and intertongues with, the Bluff Sandstone of the Morrison

Formation (figure 4, 5). They also noted that the Salt Wash and Tidwell Members correlated laterally with the Bluff Sandstone. This is in keeping with their correlation of the Recapture with the basal Brushy Basin Member above the Salt Wash Member to the north (Turner and Peterson, 2004, 2010a). In this scenario, the Westwater Member would pinch out between the Recapture Member and the overlying Brushy Basin Member to the north.

Miller (1955a) mapped the northern limit of the Recapture Member on the west side of Black Mesa south of State Route 95 at about the latitude of the Butler Wash Track Site (figure 2). Additionally, on the east side of Black Mesa, he mapped its northern limit in Cottonwood Wash only about 0.5 miles north of the type section of the overlying Westwater Member of the Morrison Formation. To the north beyond this point, Miller (1955a) mapped the combined Recapture and Westwater Members as the lower Morrison Formation. O'Sullivan (1998, 2000) replaces the Recapture Member with the Salt Wash Member at approximately this same position, but extends the Westwater Member several miles further north. O'Sullivan (2000) recognizes several prominent sandstone channels within the Recapture Member east of Black Mesa that he considers of be of Salt Wash morphology.

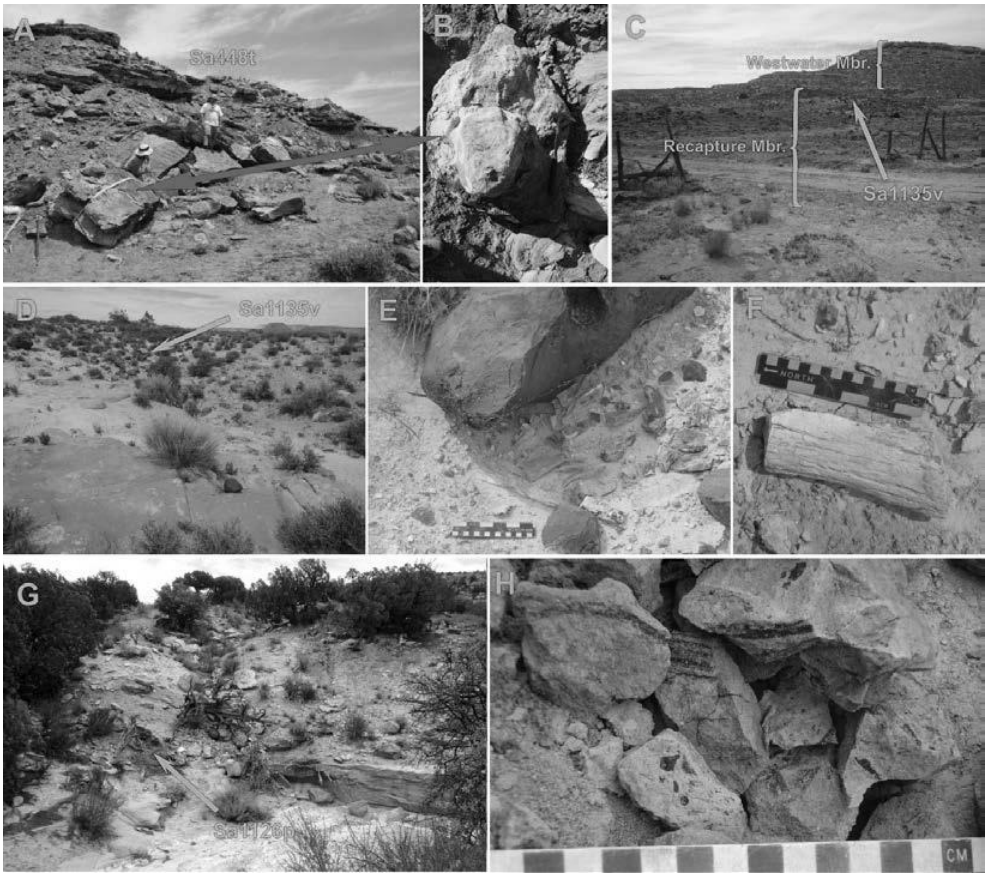

Figure 7. Other fossil localities in the lower Morrison Formation. (A) *Deltapodus* (stegosaur track) locality (Sa448t) in the Recapture Member. View from south. Double headed red arrow indicates position of *Deltapodus* bearing block on slope below site. (B) Natural cast of *Deltapodus* track. (C) Overview of shattered dinosaur limb bone site in Recapture Member on northwest side of Decker Cove (Sa1135v). View from road to west. (D) Overview of shattered dinosaur limb bone site on northwest side of Dexter Cove (Sa1135v). View from

south. (E, F) Limb bone fragments at Sa1135v. (G) Overview of plant debris bed in Westwater Member (Sa1126p). (H) Detail of fine sandstone fragments preserving carbonaceous plant debris at Sa1126p.

We identified several dinosaur sites in the Recapture Member (figures 6, 7) adding credence to its inclusion within the Morrison Formation, as no dinosaur remains are known from the San Rafael Group. It is noteworthy that the lower portion of the Morrison Formation preserves most of the known dinosaur and invertebrate remains to the southwest in northern Arizona, where the Brushy Basin Member has largely been stripped off below the basal Cretaceous unconformity (Harshberger and others, 1957). This pattern seems to be like that in the southwestern Blanding Basin, where we identified several sites in the Recapture Member and none in the overlying Westwater Member. The abundance of dinosaur bones a short distance above the Bluff Sandstone leads us to reject the Anderson and Lucas (1996, 1998) hypothesis.

Most fossil sites in the lower Recapture Member to the south and west of No-Mans Island consist of scattered small bone chips associated with a thin (< 2 ft), light-gray-colored sandy interval a few tens of feet above the top of the Bluff Sandstone (e.g., Sa1131v, Sa1132v, figure 6G-I). One locality (Sa1115v; figure 6A-F) preserved several bones along a single bedding plane and appears to be deserving of additional scientific examination. The fragmented remains of a large isolated dinosaur limb bone were identified on the west side of Decker Cove (Sa1135v, figure 7C-F). It is noteworthy that the only Morrison locality that has been published on from the study area is a natural cast of a stegosaur track referred to the ichnogenus *Deltapodus* (Milán and Chiappe, 2009). This study was the first report of this track type in the Jurassic of North America. This locality, Sa448t (figure 7A, B), is in an area that we did not investigate in the extreme southeastern part of the study area (figure 1). However, we were able to determine that the locality is in the Recapture Member.

Tidwell Member

The Tidwell Member was named for Tidwell Bottoms along the San Rafael River in Emery Country and was used on a number of unpublished geological maps produced by Robert Young for the U.S. Department of Energy (Peterson, 1988). O'Sullivan (1984) defined the Tidwell Member of the Morrison Formation as the relatively thin (~ 10 m) interval of light gray colored sandstones and sandy shales spanning the slope from their J-5 unconformity up through the base of the first laterally extensive fluvial sandstone of the overlying Salt Wash Member, with a type section on the west side of Dumas Point in Grand County, Utah (NE1/4, NE1/4, SW1/4, and SE1/4, SE1/4, NW1/4. sec. 30, T. 23 S., R. 18 E**)**. O'Sullivan (1984) described the lithology of the Tidwell Member as:

> "…. somewhat varied. Siltstone is the dominant rock type. Chert beds as much as 1.5 m thick, rounded limestone nodules, and gray limestone beds are conspicuous lithologic features of the Tidwell Member. Gypsum is also present in some abundance from the San Rafael Swell to just east of the Green River. Gray ledge-forming sandstones as much as 2 m thick, in which bedding is absent or not apparent, crop out at many localities; light-gray crossbedded channel sandstone beds typical of the overlying Salt Wash Member are absent at most places, but where present form a minor lithology in the slope-forming Tidwell Member. At places, the Tidwell contains persistent thin ledge-forming sandstone beds, generally less than 1 m thick, which are blocky, ripple marked, and commonly carry coarse grains of chert. A widespread sandstone, termed for convenience bed A, marks the base of

> the Tidwell Member at most places. Throughout large areas of east-central Utah, bed A is generally less than 0.5 m thick but locally is as much as 2.5 m thick. Here and there the bed contains coarse grains, is ripple marked, and tends to form a resistant ledge that overhangs the J-5 unconformity and underlying rocks."

Complicating the story, Peterson (1988) independently defined the Tidwell Member using another type section located 3 to 6 miles south of Tidwell Bottoms and 15 miles southwest of Green River, Utah. In this area, authigenic chert and gypsum beds characterize the lower few meters of the section, instead of O'Sullivan's bed A, which he uses as a marker for the J-5 unconformity. Stratigraphically, O'Sullivan's (1984) and Peterson's (1988) type sections are essentially correlative and so do not confuse the use of the term Tidwell in this area. Interestingly, Peterson (1988) did not reference O'Sullivan (1984) regarding the Tidwell Member, but did acknowledge O'Sullivan's paper in his discussion of the type section of the overlying Salt Wash Member.

We observed that stromatolites preserved in dark-gray limestone are associated with several of the laterally extensive lower sandstone beds including the basal sandstone bed of the Tidwell Member in a broad area between the Blue Hills westward to Duma Point (Kirkland and DeBlieux, 2017). These algal limestone beds appear to be present in the red beds in the upper portion of the underlying Summerville Formation as well. Given the presence of extensive gypsum beds along the Summerville-Tidwell contact laterally such as at Tidwell Bottoms (Peterson, 1988), we interpret this transition between the San Rafael Group and the Morrison Formation to represent the higher energy intertidal zone of a clastic sabkha (Thompson and Meadows, 1997; Saleh and others, 1999) and not the presence of a regional J-5 unconformity (O'Sullivan, 1984; Turner and Peterson, 2004). We interpret O'Sullivan's (1984) bed A as representing the normally quiet-water sabkha's waterline, occasionally agitated by storms such that coarser grains are winnowed out of the sediment forming bed A.

O'Sullivan (1984) noted that the upper contact of the Tidwell Member may be difficult to place because of intertonguing between the Salt Wash and Tidwell Members. We observed that less laterally extensive sandstone channels of Salt Wash aspect occur in the upper half of the Tidwell Member. These observations would preclude placing a J-5 unconformity at the base of the first Salt Wash sandstone bed as has been proposed by Anderson and Lucas (1996, 1998).

It is important to note that, while Peterson (1988; Turner and Peterson, 2004) had recognized the Tidwell Member as a member of the Morrison Formation in the Blanding Basin at the southern end of the study area in place of a lower Recapture Member, they currently identify an undivided Recapture Member as resting directly on the Bluff Sandstone in this area (as discussed above; figure 4). North of SR-95 the Tidwell Member replaces the Bluff Sandstone (figure 2) within the study area (O'Sullivan, 1998, 2000). At his Black Steer Mesa section on the northwest corner of the study area O'Sullivan (1998) recognizes his bed A of the Tidwell Member at the basal contact of the Morrison Formation. While no fossils were found at the base of the Morrison Formation in the northern part of the study area and the Tidwell in this area was not examined, the Tidwell is known to preserve the oldest Upper Jurassic sites, the oldest North American sauropod *Dystrophaeus*, and the only known Oxfordian-age sites in North America (Gillette, 1996a, b: Turner and Peterson, 1999; Foster, 2007; Trujillo and Kowallis, 2015; Kirkland and DeBlieux, 2017). Any identifiable dinosaur fossils from this unit are of considerable significance.

Salt Wash Member

Lupton (1914) first described the Salt Wash Member from the west side of Salt Wash, Grand County, Utah (NW1/4, sec. 19, T.23 N., R. 18 E.). Gregory (1938) provided an excellent summary:

> "In reports on the geology of the region north of Moab and other places in east-central Utah Lupton (1914) described a coarse-grained "gray conglomeratic sandstone", in places lenticular and cross-bedded, that forms cliffs about 350 feet from the top of the Morrison strata sufficiently uniform and persistent to serve as a datum plane for mapping. For this sandstone he proposed the name "Salt Wash member of the McElmo formation." As classified by Gilluly and Reeside (1928) the Salt Wash sandstone member lies at the base of the Morrison and includes not only gray conglomeratic sandstones but also clay, limestone, and gypsum. Baker (1933) defines this member as "white conglomeratic sandstones interbedded with red sandy mudstones and red shale" that occupy the lower half of the Morrison south of Moab."

Craig and others (1955) followed Stokes (1944) in extending the Salt Wash Member into the Recapture Member as defined by Gregory (1938) across the four Corners Region of the Colorado Plateau as summarized below:

> Gregory (1938) did not recognize the Salt Wash member in the southeastern corner of Utah, but subsequently Stokes (1944) recognized the member in the lower part of Gregory's Recapture member in this area as well as in the Carrizo Mountains area of northeastern Arizona. The extension of the Salt Walsh member as a recognizable unit through southeastern Utah and into northeastern Arizona and northwestern New Mexico constitutes a restriction of Gregory's original definition of the Recapture member.

O' Sullivan's (1984) plot of the type section of the Salt Wash Member is in the same location noted by Lupton (1914). However, the proposed site of the type section by Anderson and Lucas (1998) is about 2 miles farther north. As with the underlying Tidwell Member, it is important to note that Peterson (1988; Turner and Peterson, 2004) recognized the Salt Wash Member of the Morrison Formation in the western portion of the Blanding Basin west of Blanding Utah separating the Tidwell from the overlying Recapture (figure 4). Turner and Peterson (2010a, b; verbal communication, 2017) now interpret the Salt Wash to onlap the Bluff Sandstone from the north, such that in the southern portion of the study area around the southern end of Black Mesa, the Recapture Member directly overlies the Bluff Sandstone and that both the Salt Wash and underlying Tidwell Members are lateral equivalents to the Bluff Sandstone. O'Sullivan (1998) plotted the Salt Wash Member as overlying the Tidwell Member in his Black Steer Mesa section at the north end of the study area (figure 2). He (O'Sullivan, 2000) noted that just to the east of the study area in the Montezuma Valley, there were isolated sandstone lenses within the Recapture Member that he identified as being of Salt Wash character providing evidence that the Salt Wash indeed interfingered with the Recapture Member as noted by Stokes (1944) and Craig and others (1955). The Recapture Member was found to be unrecognizable as a mappable unit at the north end of Black Mesa (figure 2) by Miller (1955a). A nearly continuous line of outcrops extends from this line northward to the Black Steer Mesa section (Cadigan,

1955; O'Sullivan, 1998), providing an opportunity to rigorously document the interfingering of the Salt Wash and Recapture Members in this area (figure 2).

The Salt Wash Member was not examined for fossils during this study. A single fossil invertebrate locality has been noted at the Black Steer Mesa section in the Salt Wash Member of the Morrison Formation from a stratigraphic section in the northeastern portion of the study area at Black Steer Knoll (Cadigon, 1952). This locality (Sa0083I) as listed in the Utah Paleontological Database is based on a passing reference to bivalve shells in the eastern wall of Cottonwood Wash east of the Indian school.

Westwater Member

While recognizing that the Westwater Member may be partially or even wholly correlative to the Salt Wash Member to the north in Grand County, Gregory (1938) established the Westwater Sandstone Member for the sandstone cliffs in the lower to middle part of the Morrison because he was uncertain as to the exact correlation of these rocks. He noted that the Westwater Member caps the mesas in the southern part of the study area across the southern Black Mesa area and around Decker Cove as later documented on the photogeological map of this area (Miller, 1955b) (figure 5). Gregory (1938) summarized the properties of the Westwater Member as follows:

> "This member is essentially a series of white sandstones composed of rounded medium to coarse grains of quartz, cemented by calcium carbonate and arranged in lenticular, irregular beds 1 to 30 feet thick. They include conglomeratic bands and stringers composed of quartz +aggregates, colored chert, concretionary masses of compact green-white clay, and rare fragments of petrified wood and dinosaur bones. Interbedded with the sandstones are red earthy soft fine-grained sandy shales perhaps better called "mudstones" that thin, thicken, or disappear in short distances. With them are associated a few thin short lenses of gray limestone conglomerate. These mudstones, which make up 8 to 20 percent of measured sections, are extremely irregular. …Unconformable contacts at the base of the Westwater Canyon member were observed at several places. Features that indicate exposure of the top beds before the Brushy Basin shale was laid down were noted in McElmo Canyon, but generally the sandstone grades upward through a series of gray sandy shales and merges into the variegated shales at different horizons….The thickness of eight measured sections of the Westwater Canyon sandstone member ranges from 222 to 295 feet.

As with the Recapture Member, the Westwater Member was applied to correlative strata across the Four Corners area, northeastern Arizona, and northern New Mexico. Whereas the USGS has maintained Gregory's usage, Anderson and Lucas (1996, 1998) proposed that the Westwater Member be dropped in favor of the Salt Wash Member. They identified Gregory's (1938) type section where Westwater Canyon joins Cottonwood Canyon (figure 2) and provided a redescription (Anderson and Lucas, 1998).

In Craig's (1955) discussion of the Morrison Formation, the Westwater Member was shown to be a wedge of coarse strata, both thickening and coarsening directly south of the study area. The presence of granitic fragments indicates it was derived directly from the south where

granites were being exposed along the central Arizona rift shoulder of the Mogollon Highlands along the north side of the Bisbee Basin (e.g., Kirkland, 1990, 1991). Genetically, these rocks can be considered similar to the coarse westerly sourced sandstone wedge (Fifty Mile Member) that replaces the Brushy Basin Member to the southwest in the southern Kaiparowits Basin (Peterson, 1988).

In our limited explorations in the southern part of the study area around Decker Cove, we note that the main cliff formed by the sandstones of the Westwater Member was separated from a smaller upper cliff that capped the mesas (following Miller, 1955b) by an appreciable slope of pale greenish mudstone that we initially identified as the overlying Brushy Basin Member. Turner and Peterson (2004) correlated this upper interval of the Westwater with the lower part of the Brushy Basin Member in its type area on the northern end of Black Mesa (figure 4). Miller (1955a) only mapped the Westwater Member south of his northern limit of the Recapture Member. On Miller's (1955a) photogeological map the usage of Westwater only extends north of its type section for approximately 0.5 miles with the Morrison from this point northward divided into a lower Morrison Formation and an upper Brushy Basin Member. O'Sullivan (2000) recognized the Westwater as extending several miles further north. Prospecting north of SR 95, we noted that the lower Brushy Basin Member appeared to be very sandy and largely devoid of significant vertebrate fossils, and we have initially concluded that Turner and Peterson's (2004) correlation of the upper interval of the Westwater with the lower Brushy Basin Member is probably correct. The complexities in correlating the southern and norther portions of the study area are daunting, but we believe correlation of this interval from south to north along the west side of the Blanding Basin is certainly plausible; that could be confirmed or refuted by tracing these surfaces in outcrop and measuring some intermediate stratigraphic sections (figure 1, 5). Because no identifiable fossils were found in this interval, this important stratigraphic question does not affect this report.

While no significant fossils were noted in the Westwater Member during this study, Gregory (1938) reports that the member does preserve dinosaur bone and petrified wood. However, a sandstone bed preserving abundant carbonaceous plant detritus (figure 7g, h) was identified in the lower Morrison Formation in a rather densely vegetated area west of the north end of Black Mesa (Sa1126p). The site was most likely in the Westwater Member. As northwestern Black Mesa is the type area of the Brushy Basin Member (figure 8) and is deserving of a detailed stratigraphic analysis, the contacts of these units will be resolved in this area eventually.

Brushy Basin Member

In establishing the Brushy Basin Shale Member for the variegated mudstone interval that forms the upper part of the Morrison Formation across the Colorado Plateau region, Gregory (1938) did not state the location for his specific type section, titling his 450-foot section of the Brushy Basin Member in his Section 25 solely as "Morrison Formation in Brushy Basin." On his geological map, Gregory (1938, pl. 1) indicated that the Brushy Basin physiographic feature extends from the southwest side of the Abajo Mountains across State Route 95 to the northwest side of Black Mesa. Brushy Basin Wash enters Cottonwood Wash well to the north of SR 95 and Google Earth indicates the Brushy Basin itself is well north of that area. Forested cover is extensive over the Brushy Basin outcrop belt north of SR 95. However, Gregory (1938, pl. 13D) did illustrate the exposures of the Brushy Basin on northwest corner of Black Mesa, where there

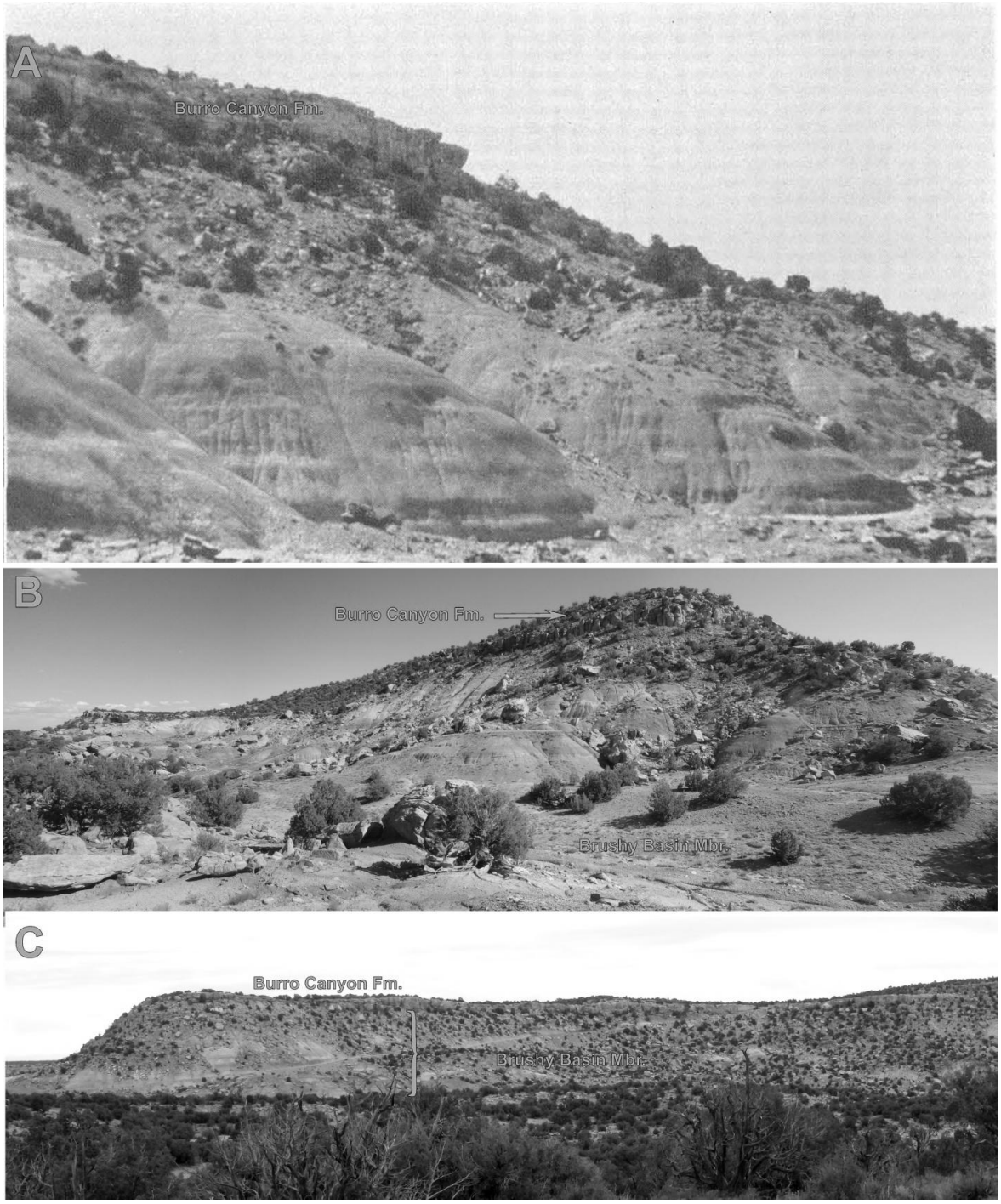

Figure 8. Type area for the Brushy Basin Member of the Morrison Formation. (A) Gregory's (1938, pl. 13D) picture of type area of Brushy Basin on "west" side of Black Mesa. (B) Northwest corner of Black Mesa viewed from north. (C) Northwest corner of Black Mesa viewed from west.

are some of the most extensive exposures of the Morrison Formation in the Brushy Basin area. It is therefore logical to assume that the northwest corner of Black Mesa was Gregory's site for the type section of the Brushy Basin Member (figure 8). The dirt road running from SR 95 to the top of Black Mesa now traverses the entire section of the Brushy Basin Member making it the most accessible exposure as well. Gregory (1938) summarized the characteristics of the Brushy Basin Member as follows:

> "The upper part of the Morrison of the San Juan country consists of the well-known variegated shales (Morrison shales, McElmo shales) that generally in Utah and western Colorado lie immediately below the Dakota (?) sandstone. In fact, they owe their preservation to the resistant Dakota cover. Directly beneath cliffs of Dakota (?) sandstone they stand in almost vertical walls; where the sandstone has been stripped "back they form slopes that continue outward into mounds and ridges spread over a platform of Westwater Canyon sandstone. Their appearance is everywhere the same brightly variegated masses that are exceeded in beauty of coloring only by the Chinle "marls." The dominant beds are white, gray, green, purple, and red sandy shales and sandstones. … Subordinate beds are gray, pink, blue, and gray limestones; conglomerates of red, green, and white cherts; and buff hard sandstones. The buff sandstone is more abundant near the base and seems to increase in amount eastward toward the Colorado line."

We recognized that the Brushy Basin Member appeared to be noticeably thicker in the Brushy Basin area than in other areas on the Colorado Plateau as confirmed by Gregory's (1938) measured section. We found that the Brushy Basin fossil sites we identified in the western Blanding Basin were in the middle and upper portions of the member, perhaps reflecting intertonguing of the Brushy Basin and Westwater Members in the lower part, supporting the Turner and Peterson (2004) correlation rather than the Anderson and Lucas (1998) correlation (figures 3, 4). To the north, in the Blue Hills area, fossil sites appear to be more evenly distributed within the Brushy Basin Member, but may be most abundant in the lower part as documented by Turner and Peterson (1999).

The Brushy Basin Member is generally the most fossiliferous member of the Morrison Formation and preserves more significant dinosaur fossil remains than nearly any other rock unit in North America (Carpenter and others, 1998; Turner and Peterson, 1999; Foster and Lucas, 2006; Foster, 2007).

A significant outcrop of the Brushy Basin Member occurs on the south end of Black Mesa where the Black Mesa Road crosses this member. Sa1113v is about one-third of a mile west of the road along this escarpment and consists of a laterally extensive bone bed with multiple bones exposed at the surface (figure 9A-E). This locality has the potential of yielding well-preserved large dinosaur remains. A few 10s of ft. higher stratigraphically there is a laterally extensive organic layer that extends across the entire area eastward to the Black Mesa Road. Sa1114v preserves common small bones in this bed and deserves a test excavation to determine if small identifiable bones are preserved here (figure 9 F-J). Even farther east this bed (Sa1133v) is a more fine-grained organic unit (figure 9 K-M) that was sampled to see if it would yield palynomorphs. The sample was processed under the direction of Dr. Carol Hotton at the Smithsonian Institution, who found it to be barren of palynomorphs. The bed was also found to contain a 5-inch-thick volcanic ash (figure 9M) under examination by Dr. Kelly Trujillo and Dr.

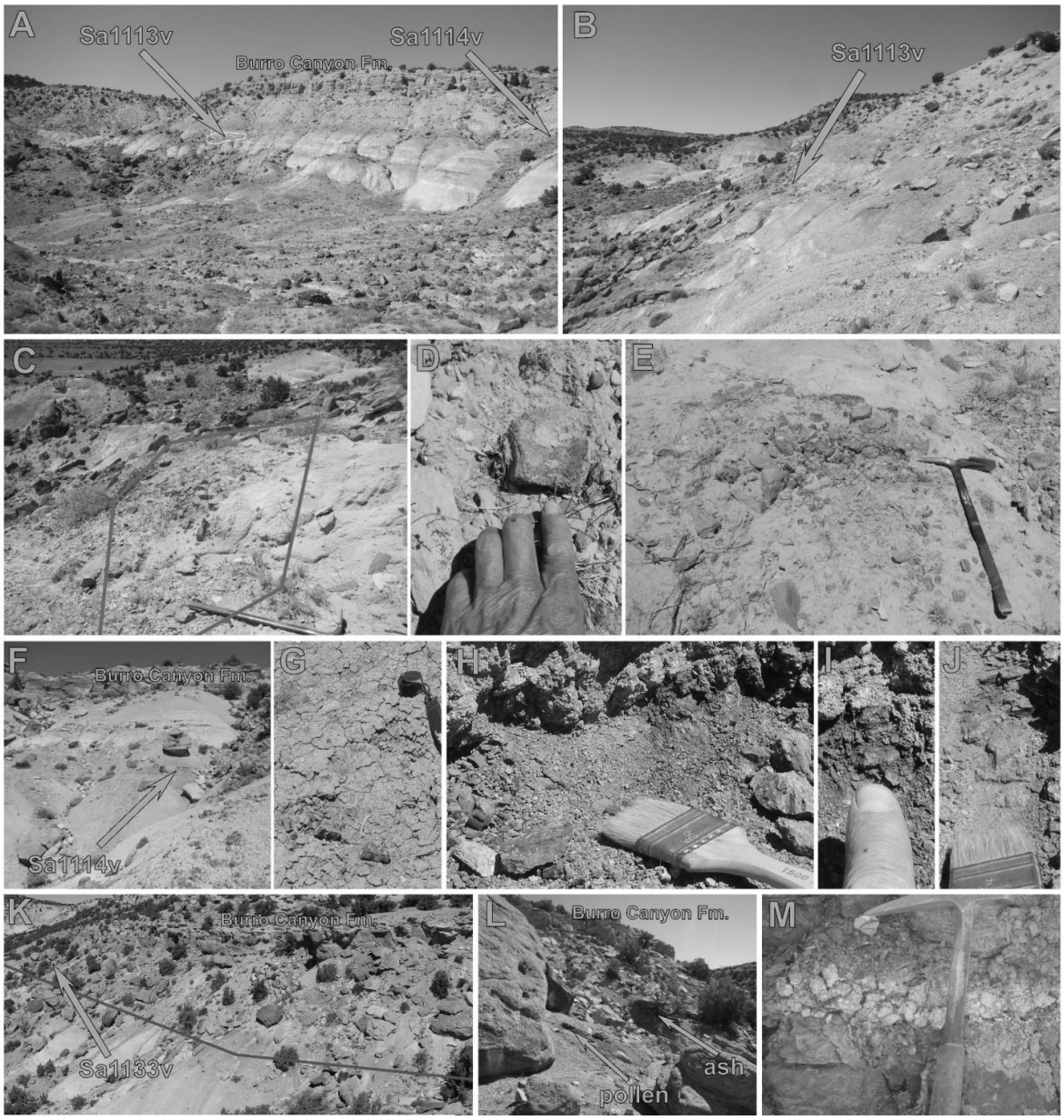

Figure 9. Brushy Basin Member of the Morrison Formation fossil localities on Black Mesa. (A) Overview of localities Sa1113v and Sa1114v. View looking northwest. (B) Overview of Sa1113v. (C E) Close up of dinosaur bones at Sa1113v. (F) Overview of Sa1114v. (G H) Close up of dinosaur bones in situ at Sa1114v. (K) Overview of locality Sa1133v. (L) Sa1133v showing location of pollen and ash bearing strata. (M) Close up of volcanic ash layer at Sa1133v. Estwing hoe pick head ~ 40 cm. Paintbrush 2 in. wide. Estwing rock hammer head ~ 18 cm.

Kent Chamberlain at the University of Wyoming, who reported to the BLM that it preserves pristine needles of zircon that yielded a highly-resolved uranium-lead age following chemical abrasion to remove the altered rind on the crystals. Chamberlain reported an age that incorporates both the $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ data, of 150.67±0.32 Ma (95% confidence limits)

from this sample (appendix 2). Trujillo (verbal communication, 2017) noted that this is the most highly resolved date for the top of the Morrison Formation (Kowallis and others, 2007; Trujillo and Kowallis, 2015).

Several sites occur in the area north and south of US 95, where it crosses the outcrop belt west of Blanding, Utah north of Black Mesa (figure 10). One site (Sa1155v) had been reported to the U.S. Bureau of Land Management north of US 95, which had been illegally excavated. We assumed that it had been worked by individuals with experience excavating bones in the Brushy Basin Member as it had been covered by a blue tarp and reburied. The smectitic mudstones of

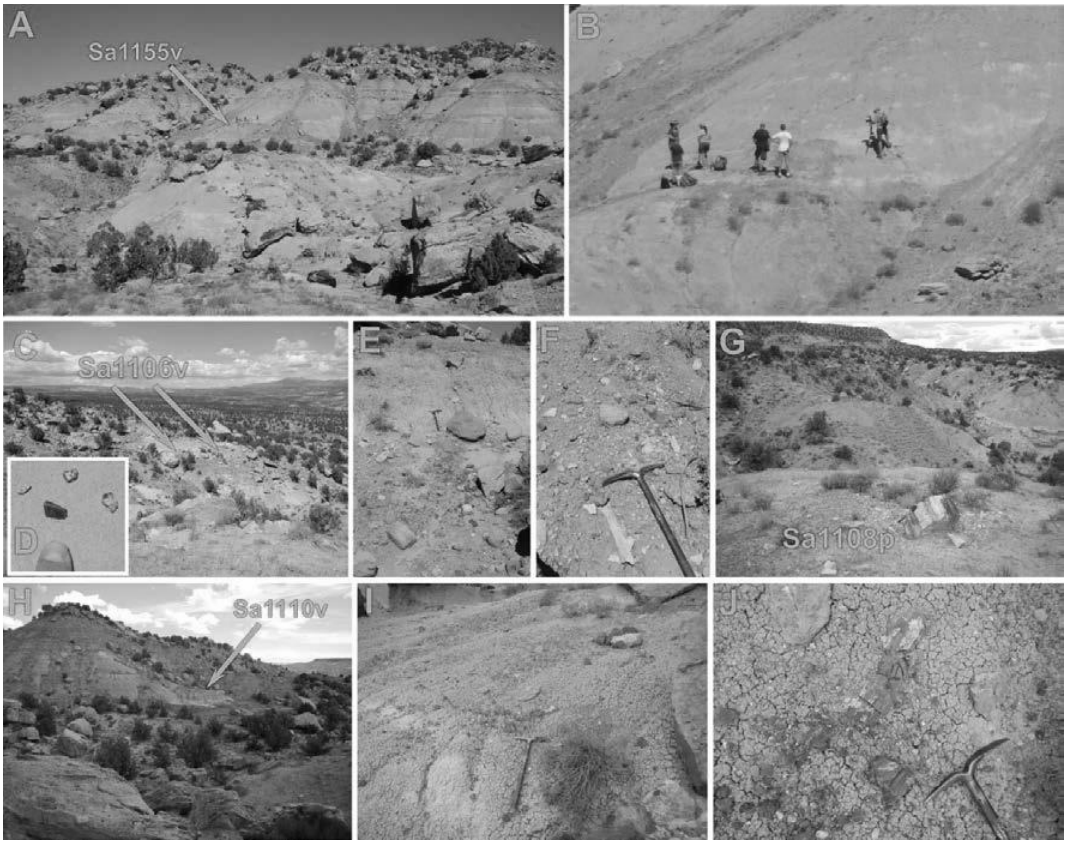

Figure 10. Fossil localities in Brushy Basin Member of the Morrison Formation on the south side of Brushy Basin Rim and the north side of Black Mesa. (A) Overview of vandalized dinosaur bone locality Sa1155v. View looking north. (B) Telephoto view of Sa1115v from the same location shown in (A). (C) Overview of locality Sa1106v showing location of bone and microfossil bearing strata. (D) *Allosaurus* tooth and small bone fragment found at Sa1106v. (E, F) Bone fragments on slope at Sa1106v. (G) Section of petrified log at Sa1108p. (H) Overview of locality Sa1110v. (I, J) Nearly complete dinosaur bone in situ at Sa1110v. Estwing hoe pick head ~ 40 cm.

the Brushy Basin are notorious as swelling clays and when dinosaur bones are partially uncovered rain will quickly destroy the bone by wetting and expanding the surrounding mudstone, which then shrinks again on drying. Repeating this process will quickly shatter even relatively well-preserved dinosaur bones. Experience shows that to preserve any bones left in situ

requires that they be protected by waterproof tarps. But even with the use of a tarp, the condensation of moisture under the tarp may still damage the bone. Therefore, uncovering bones in the Brushy Basin Member should not be done unless the intent is to immediately document the position of the bones and collect them. A BLM crew salvaged the few damaged bones present at the site while we were doing our survey (figure 10 A, B). Many other vertebrate sites identified in this area consist mostly of bone scatters that represent bones weathering out on the surface (e.g., Sa1106v, Sa1110v; figure 10C-F, H-J). Petrified wood was also identified such as Sa1108p (figure 10 G).

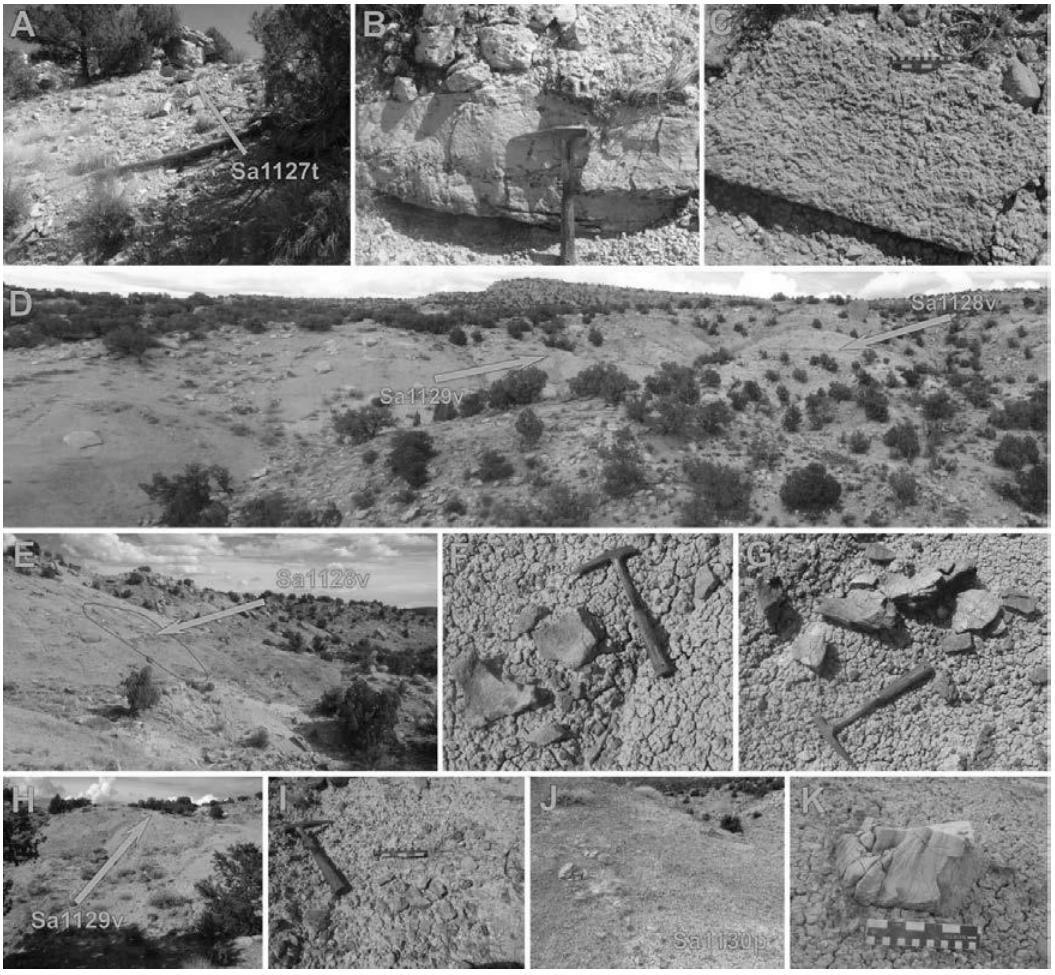

Figure 11. Fossil localities in Brushy Basin Member of the Morrison Formation on the west side of Brushy Basin Rim. (A) Overview of Sa1127t. (B) Lateral view of trace fossils preserved in crevasse splay at Sa1127t. (C) trace fossils preserved on underside of crevasse splay block below Sa1127t. (D) Overview of the relative positions of Sa1128v and Sa1129v as viewed from the south at Sa1130p. (E) Extent of scatter of large dinosaur bone fragments at Sa1128v as viewed from west. (F, G) Large bone fragments on surface at Sa1128v. (H) Sa1129v at top of slope as viewed from south. (I) Sauropod vertebral fragments weathering out in situ at Sa1129v. (J) Petrified in situ stumps preserved at Sa1130p. (K) Stump preserved in situ at Sa1130p.

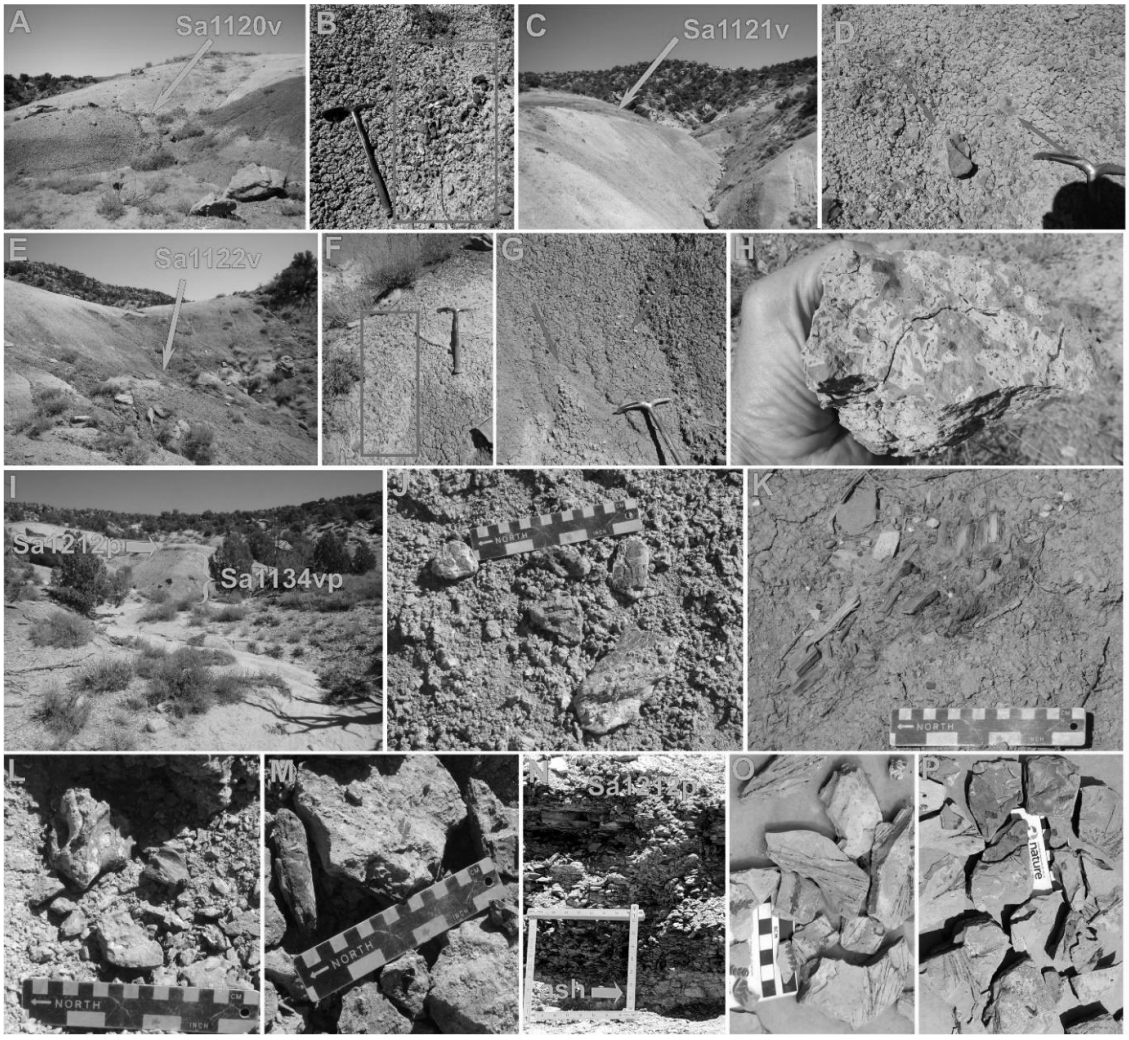

Figure 12. Fossil localities in Brushy Basin Member of the Morrison Formation in Brushy Basin on the northwest side of Brushy Basin Rim. (A) Overview of locality Sa1120v. (B) Bone fragments eroding down slope at Sa1120v. (C) Overview of locality Sa1121v. (D) Bone fragments at Sa11121v. (E) Overview of locality Sa1122v. (F) Bone fragments eroding from slope at Sa1122v. (G) Close up of in situ fossil bone at Sa1122v. (H) Termite or ant nest? at Sa1122v. (I) Overview of plant debris bed at locality Sa1134v and overlying compressional fossil plant locality Sa1212p. (J) Close up of bone fragments initially found at Sa1134v. (K) Petrified wood exposed at Sa1134v. (L, M) Bone and plant fragments at Sa1134v. (N) Closeup of volcanic ash underlying Sa1212p. (O, P) Typical fossils preserved in Sa1212p.

Outcrops of the upper Brushy Basin Member farther north between Brushy Basin Wash and the ridge forming the Brushy Basin Rim include more fossil sites with isolated dinosaur bones and pieces of petrified wood (figure 11, 12; appendix 1). High in the Brushy Basin Member west of the northernmost end of the Brushy Basin Rim a thick organic plant debris bed was identified (Sa1134vp). Several meters thick, this site appeared to cross the valley floor for approximately 100 m. The site preserved copious amounts of carbonaceous plant material with petrified driftwood and bone (figure 12 I-P). This bed is very different than other plant-bearing beds in the Morrison Formation, which are generally dark-gray mudstones with more

disseminated plant material (Parrish and others, 2004; Kirkland, 2006). It resembles the plant debris beds in the Lower Cretaceous Wessex Formation of England, which are famous for the abundance and diversity of the flora and fauna they preserve (Martill, 2001; Sweetman and Insole, 2010). The UGS obtained a permit to conduct a test excavation in May 2017 to evaluate the paleontological potential of this locality. This resulted in the recognition of a paleobotanical site preserving abundant *Czekanowskia*, diverse ferns, conifer shoots, coprolites & uncommon conchostracans in a finely-bedded shale at the top of the exposure overlying a 4-in. thick volcanic ash (sampled). Carbonaceous compressional plant fossils are particularly rare in the Morrison Formation with less than 10% of the identified pollen and spore types represented by macroscopic plant remains (Parrish and others, 2004; Kirkland, 2006). This compressional plant horizon was considered to be significant and was given its own locality number Sa1212p (figure 12 I, N-P)

Burro Canyon Formation

The Burro Canyon Formation was not a major focus of this inventory because it is not known to contain many vertebrate fossils, but this was also true of the correlative (and highly fossiliferous) Cedar Mountain Formation until the last 25 years (e.g., Kirkland and others, 2016). In 1948, Stokes and Phoenix (1948) described the Burro Canyon Formation as a mappable Lower Cretaceous unit of pebbly channel sandstones and green floodplain mudstones near Slick Rock in west-central Colorado. The Burro Canyon Formation was distinguished on the basis of thickness, pebble size, and paleocurrent directions (Craig, 1981). According to Stokes (1952), the Burro Canyon Formation was deposited atop the Upper Jurassic Morrison Formation and formed a broad alluvial plain deposited by rivers flowing from highlands to the south. Young's (1960) proposal that the correlative Burro Canyon Formation be considered as simply a southern and eastern extension of the Cedar Mountain Formation has not been adopted. The Colorado River has been used as the defining line in Lower Cretaceous rocks between the Burro Canyon Formation and the Cedar Mountain Formation to the northwest.

Ferruginous paleosols representing wet climatic conditions appear to be characteristic of the transition between the underlying Morrison Formation and basal conglomeratic sandstone beds at the base of the cliff-forming Burro Canyon Formation in this area (figure 13 A-D). Similar beds in this position to the north in the basal Cedar Mountain Formation were found to be Cretaceous in age based on preserved dinosaur remains (Kirkland and others, 2016), and deserve more investigation.

No vertebrate body fossil sites are known in the Burro Canyon Formation in Utah. However, recently a diverse dinosaur tracksite (Milán and others, 2015) has been recognized in these beds east of the study area (figure 2). These natural molds of a diversity of dinosaur taxa were revealed by road construction and have been dated by detrital zircons as having a maximum age of 131 Ma. Only burrowed intervals representing the terrestrial *Scoyenia* ichnofacies were recognized during one partial day of examining the Burro Canyon Formation on the north end of Black Mesa (figure 13 E-J).

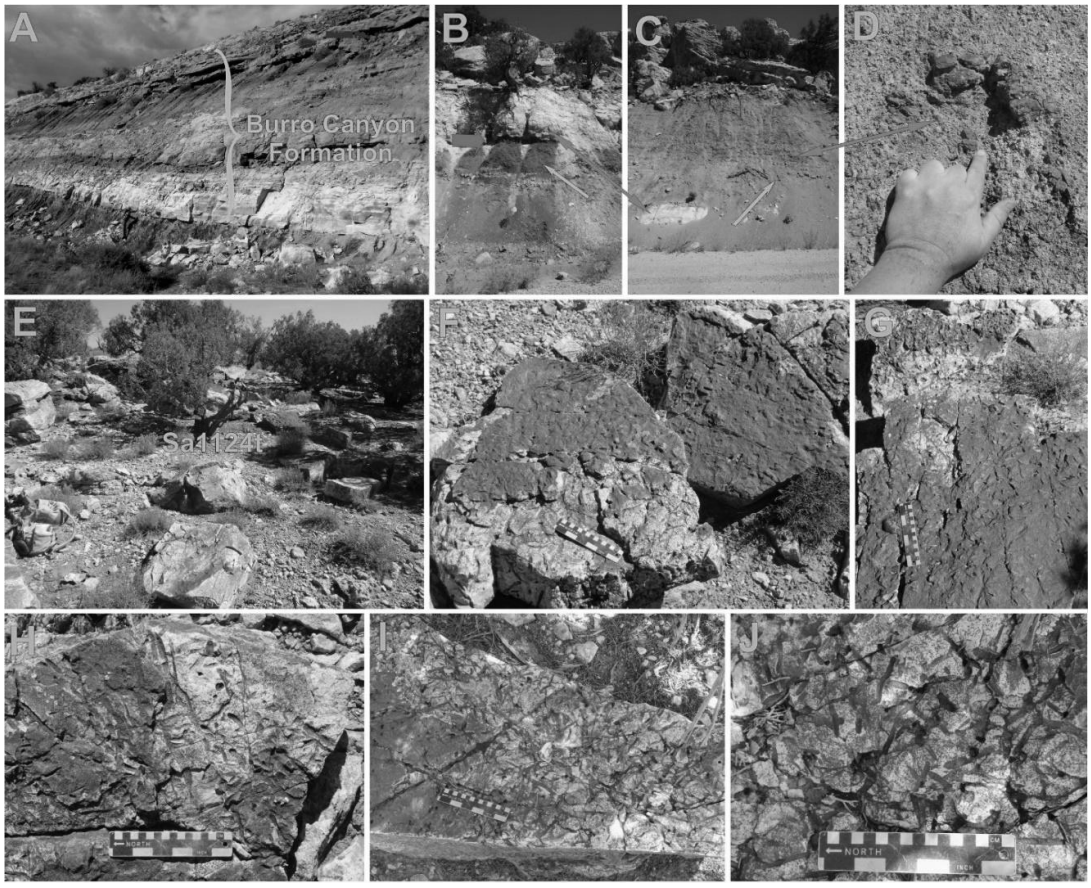

Figure 13. Burro Canyon Formation. (A) Burro Canyon Formation at the jumpoff on west side of Highway 191 between Bluff and Blanding, Utah. (B) Contact between Morrison and Burro Canyon Formations on road up the northwest side of Black Mesa as indicated by stout horizontal red arrow at base of white sandstone. Yellow arrow indicates standard rock hammer. Double headed red arrow indicates correlation of white sandstone at base of Burro Canyon Formation with that in C. (C) Burro Canyon outcrop on the road up northwest side of Black Mesa. Yellow arrow indicates standard rock hammer. Double headed red arrow indicates position of ferruginous paleosol detailed in D. (D) Ferruginous paleosol. (E) Overview of exposed quartzite sandstones preserving *Scoyenia* ichnofacies at top of the Burrow Canyon Formation on northwest side of Black Mesa (Sa1124t). (F J) *Scoyenia* ichnofacies preserved in hard quartzite at Sa1124t.

Conclusions

A number of significant sites were recorded over a 10-day interval in a small portion of the exposed medial Mesozoic along the western margin of the Blanding Basin. The Morrison Formation in this area is significant in being the type area for several members of the Morrison Formation and represents one of the most southern outcrop areas for which significant fossil remains have been identified. Most of the vertebrate sites encountered represent isolated bones in the Recapture and Brushy Basin Members, although a few sites that may represent bone beds were also identified, which deserve to be tested for potential future excavation. Petrified logs and stumps were encountered at a number of sites within the Brushy Basin Member as were a few interesting plant debris sites. The overlying Burro Canyon Formation was barely looked at and as such its potential in the region currently cannot be defined.

Acknowledgments

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